TOPIC 5
MINERALS AND ROCKS

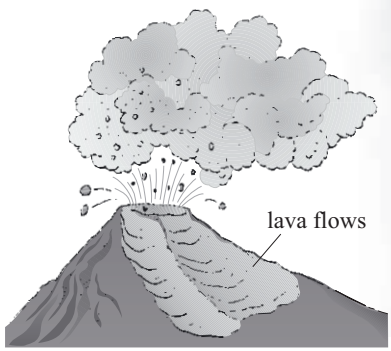
5.1 Rock formation and features

Note to S282 students: this section relates to material in S283.

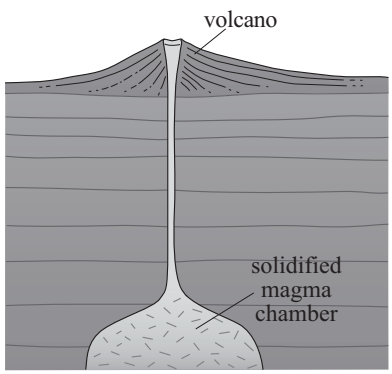
A **rock** is a *solid* assembly of mineral grains. A **mineral** is a solid material, formed by a natural process, with a *chemical composition* that falls within certain narrow limits. Its constituent atoms are arranged in a regular three-dimensional array and this determines the characteristic shape of the *crystal*. A rock may consist of just one type of mineral, but more usually it contains several different types. Mineral grains can be intact crystals or fragments, and can vary in size from a few micrometres to a few centimetres.

Different types of rocks form in different ways, and the processes of formation and any subsequent activity leave their marks on the rocks. The rocks that make up the Earth's surface are manifestations of the Earth's activity, and on other rocky bodies (planets or natural satellites) so rocks provide important clues to any activity or lack thereof. There are three main processes of rock formation, each of which produces characteristic features in the resulting rock.

Rocks that have solidified from a molten state are **igneous rocks**. On Earth, heating deep in the planet's interior to temperatures around 1000 °C produces **magma** (which is molten rock). Magma may emerge onto the Earth's surface via a volcanic eruption, in which case it is known as **lava**. The rock thus formed is called an extrusive igneous rock (Figure 5.1a). Alternatively magma may cool slowly while still underground forming so-called **intrusive** igneous rock as in Figure 5.1b. As the magma cools, crystals grow from the liquid. The rocks that form underground may eventually be uncovered, as overlying rocks become worn away and deposited elsewhere. Igneous rocks are characterized by the presence of complete crystals and their size indicates the rate at which the magma cooled: in general, large crystals are produced by slow cooling.



(a)



(b)

Figure 5.1 Igneous rock forms when (a) magma erupts onto the Earth's surface or (b) cools underground.

Sedimentary rocks are formed by the deposition of layers of sediments. The sediment might originate if rocks have been broken up by **weathering** (exposure to rain, wind and frost) and the resulting small fragments have been transported by water, wind or glaciers to be deposited elsewhere in roughly horizontal layers known as **strata**. The strata often include shells and skeletons of marine organisms. The grains of sedimentary rocks are usually fragments rather than complete crystals, and the presence of fossils generally indicates a sedimentary rock.

The third main group of rocks is called **metamorphic** (meaning 'changed form'). A metamorphic rock is formed when any type of rock is heated to temperatures of several hundred degrees Celsius and/or subjected to high *pressure* because of the *weight* of overlying rocks. Unlike igneous rocks, metamorphic rocks do not cool from a *liquid*; rather, the change occurs while the rock remains in the *solid* state.

During metamorphism, the atoms in the minerals making up the rock become reorganized, sometimes resulting in the formation of new minerals and changing the rock's appearance while maintaining the same *chemical composition*. Metamorphic rocks, like igneous rocks, are crystalline, but the process of metamorphism often results in banding or alignment of minerals.

QUESTION 5.1

What is wrong with each of the following statements?

(i) A mineral is another name for a rock.

(ii) A rock that contains whole crystals is likely to be a sedimentary rock.

(iii) Igneous and metamorphic rocks differ only in the way they were formed and are indistinguishable in appearance.

5.2 Common minerals and rocks

5.2.1 Rock-forming minerals

More than 3500 different *minerals* have been identified at the Earth's surface, but the number of common *rock*-forming minerals is much smaller. The *chemical composition* of a mineral depends on the *elements* available for its formation. Table 5.1 lists the most abundant elements in the Earth's crust.

Table 5.1 The composition of the Earth's crust.

Element	Symbol	% by mass
oxygen	O	46.6
silicon	Si	27.7
aluminium	Al	8.3
iron	Fe	5.0
calcium	Ca	3.6
sodium	Na	2.8
magnesium	Mg	2.1
all others		1.3

Minerals containing oxygen combined with silicon are the most common minerals at the Earth's surface. Some of these, such as quartz, are almost entirely silicon dioxide (SiO_2) with traces of other elements, but the most common are **silicates**, in which silicon and oxygen are grouped together as SiO_4 and combined with one or more metals.

Other important minerals include **carbonates** (containing the CO_3 group). The mineral calcite is calcium carbonate. On Earth the *sedimentary* rocks limestone and chalk, which can originate from the shells of living organisms (chalk and some limestones) or by chemical precipitation (some limestones), are also largely calcium carbonate. Many minerals are *oxides* (such as haematite) which contain metal atoms combined with oxygen.

While minerals have a fairly well-defined chemical make-up, many crystal structures can accept small variations in composition. For example, the mineral olivine is composed of magnesium and/or iron combined with the silicate group SiO_4. Its *chemical formula* is written $(Mg, Fe)_2SiO_4$, showing that for every SiO_4 group there are two metal atoms, but the proportions of magnesium and iron can vary from specimen to specimen.

Mineral formation is also affected by physical conditions (temperature and pressure) which influence the *crystal* structure adopted by the atoms. It is therefore possible to have two or more different minerals with the same chemical composition, but with different structures.

QUESTION 5.2

Suggest at least two reasons why minerals are generally referred to by name (e.g. quartz, haematite) rather than by their chemical formulae.

5.2.2 Common rock types

On Earth, the most common *igneous* rock types include **basalt** and **granite**. Basalt is an *extrusive* igneous rock, formed by rapid cooling and crystallization. Its rapid cooling leads to a fine grain structure. Chemically it contains quite a high proportion of the metals magnesium, calcium and iron, combined in various minerals with the elements oxygen and silicon.

Granite, by contrast, is in an *intrusive* igneous rock which has cooled slowly underground. It contains relatively small amounts of calcium, iron or magnesium, but quite large proportions of silicon, sodium and potassium. Its slow cooling ensures that the mineral grains are large, giving the rock a coarse texture.

Sedimentary rocks rely on a variety of processes for their formation. On Earth, rain, wind and glaciers bring about weathering and erosion, and then the transportation of the resulting fine fragments which are deposited elsewhere to form new rocks. Common sedimentary rocks on Earth include (in order of decreasing grain size) **conglomerates**, **sandstones** and **mudstones**. Chemically, their composition varies according to that of the original rock. Conglomerates contain mainly pebbles and rock fragments. Sands are composed mainly of mineral grains (especially quartz) or broken shells of organisms. The shelly material consists largely of calcium carbonate and forms **limestone** deposits. Muds contain clay minerals (which are *silicates*) and organic matter and, if buried under further deposits, become compacted to form **shale**.

Slate and **marble** are examples of *metamorphic* rocks found on Earth. Slate originates from shale, a sedimentary rock that has been heated to 200 to 350 °C at depths of 5 to 10 km below the Earth's surface. Heating at greater temperatures and pressures produces **gneiss**, which has much coarser grains than slate but whose chemical composition still reflects that of the silicates of the original mud. Marble originates from limestone and generally contains only one mineral, calcite, which is a form of calcium carbonate.

QUESTION 5.3

Complete Table 5.2 by putting a tick (✓) in appropriate cells so that the table summarizes the origins and some key features of the rock types listed.

Table 5.2 Table for Question 5.3.

	limestone	granite	slate	basalt	marble
igneous					
sedimentary					
metamorphic					
fine-grained texture					
contains mainly carbonates					

5.3 Answers and comments for Topic 5

QUESTION 5.1

(i) A rock is made up of minerals, usually a mixture of several types. A mineral has a well-defined chemical composition and a crystal structure, but a rock has neither.

(ii) A rock containing whole crystals is like to be igneous or metamorphic. A sedimentary rock is more likely to be made up of crystal fragments.

(iii) Igneous and metamorphic rocks do indeed form in different ways: igneous from molten rock and metamorphic from changes brought about in the solid state. Metamorphic rocks can usually be distinguished from igneous rocks by the banding or alignment of crystals found in metamorphic rocks.

QUESTION 5.2

Reasons include:

- the chemical composition of some minerals can vary slightly from specimen to specimen;
- minerals may have quite different properties arising from their crystal structure while having the same chemical composition;
- mineral names tend to be shorter and more memorable than complex chemical formulae.

QUESTION 5.3

See Table 5.3.

Table 5.3 The answer to Question 5.3.

	limestone	granite	slate	basalt	marble
igneous		✓		✓	
sedimentary	✓				
metamorphic			✓		✓
fine-grained texture	*		✓	✓	*
contains mainly carbonates	✓				✓

* Many limestones and marbles can have a fine-grained texture.